

Geothermal Environmental Sustainability.

Pisa, Italy.

May 7, 2018

# Human health aspects related to geothermal energy

Michael N. Bates, Ph.D.

School of Public Health  
University of California, Berkeley

Health concerns around geothermal sites are mainly associated with:

- Air pollution
- Water pollution

# Geothermal gases

- Carbon dioxide
- **Hydrogen sulfide**
- Water vapor
- Methane
- Nitrogen
- Hydrogen
- Mercury vapor
- Radon

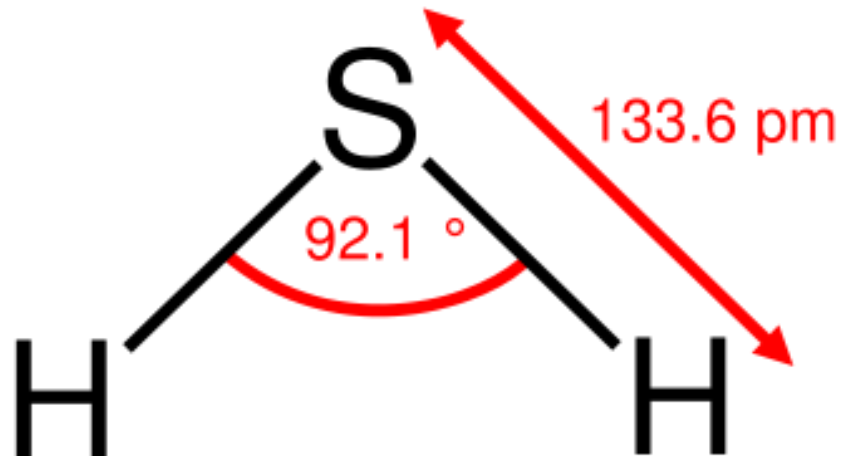
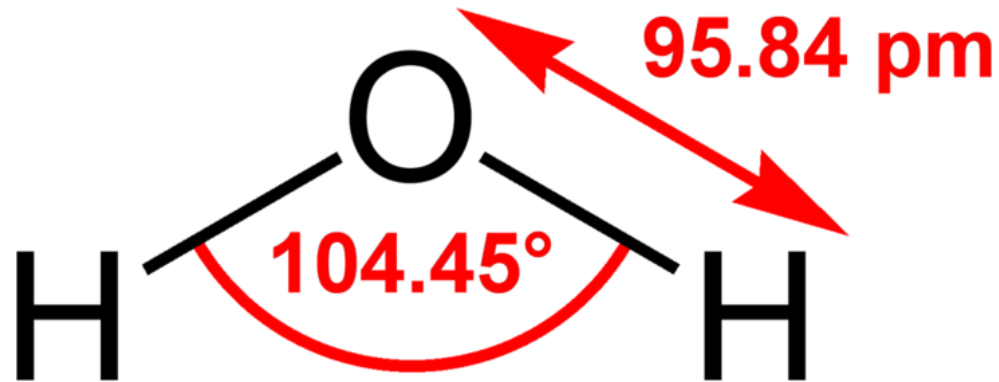
# Periodic Table of the Elements 2006

1 H 1.01																	18 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 15.99	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (270)	109 Mt (268)	110 Ds (281)	111 Rg (272)							

See "It's Elemental: The Periodic Table"  
<http://pubs.acs.org/cen/80th/elements.html>

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

# Hydrides of Group 16 of the Periodic Table



# Acute health effects of H<sub>2</sub>S

## Concentration (ppb)

3-20

10,000-50,000

50,000-100,000

100,000-150,000

230,000-500,000

500,000-1,000,000

## Effects

Odor threshold

Eye irritation

Respiratory irritation,  
eye damage

Loss of smell, severe  
irritation

Pulmonary edema

Respiratory paralysis  
& death

The key outstanding question for H<sub>2</sub>S:

What are the health effects, if any, associated with long-term exposure to low levels of H<sub>2</sub>S (e.g., < 3,000 ppb)?

# Main known mechanism of H<sub>2</sub>S toxicity

- Prevention of mitochondrial respiration by inhibition of the cytochrome c oxidase (CCO) enzyme
- CCO is critical for cellular production of adenosine triphosphate (ATP), which supplies energy for biochemical reactions in the body
- Inhibition of the CCO enzyme leads to “chemical asphyxiation” of cells.



# Sources of low-level H<sub>2</sub>S exposure

- Paper mills
- Sewage treatment plants
- Oil and gas refineries
- Animal slaughterhouses
- Landfills
- Concentrated animal feeding operations (CAFOs)
- Volcanic and geothermal areas

# Difficulties in studying the health effects of long-term, low-level exposure to H<sub>2</sub>S

- The number of people exposed to H<sub>2</sub>S in most situations is small
- There are other potentially toxic exposures at the same time
- Exposures vary widely over time and are difficult to measure
- There are barriers to investigation because of concerns about legal liability

“...studies should be initiated among the general population in a geothermal area, taking advantage of the natural conditions provided, for example, by the situation in Rotorua, New Zealand.”

International Programme on Chemical Safety  
Environmental Health Criteria 19: Hydrogen sulfide  
WHO: Geneva, 1981



## The Pacific “Ring of Fire”

Source: Hansell et al., Occup Env Med 2006; **63**:150

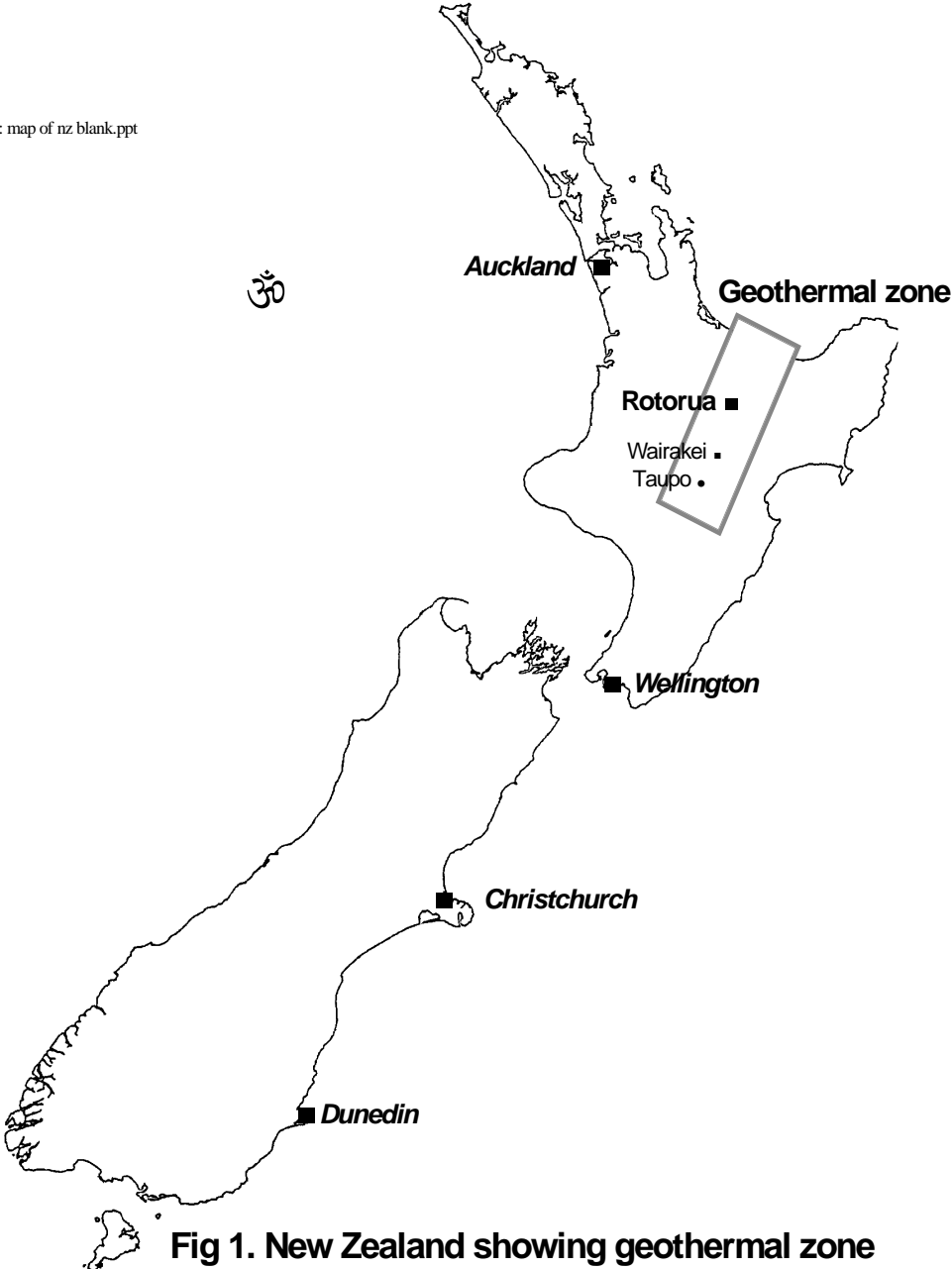
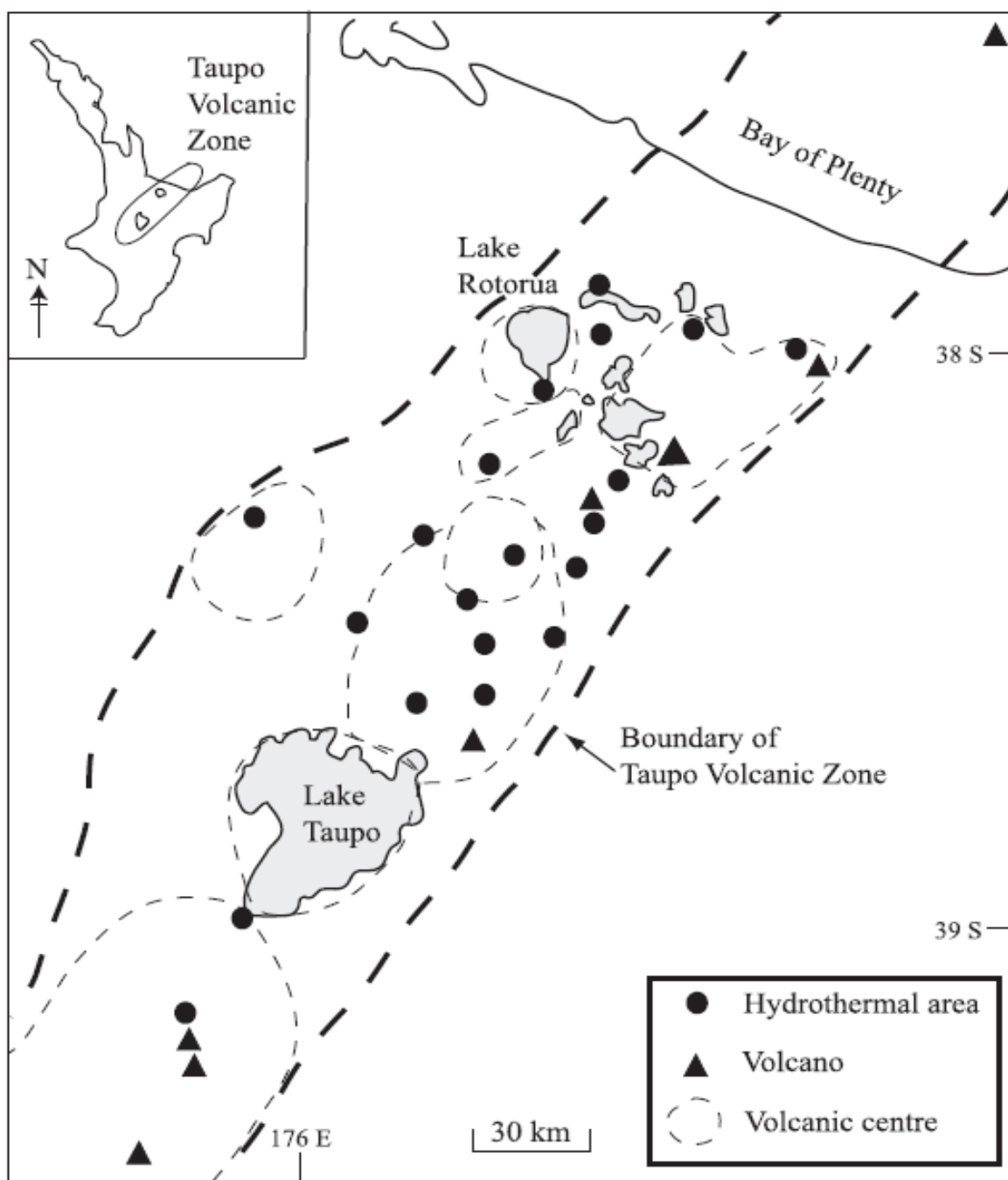


Fig 1. New Zealand showing geothermal zone



Horwell CJ, et al. (2005)  
*J Volcanol Geothermal  
 Research*  
 139:259–26

Fig. 1. Map of Taupo Volcanic Zone showing volcanic centres and geothermal areas.

# Rotorua city



è











Rotorua Bath House (about 1906)

# The recent study in Rotorua:

- Funded by the U.S. National Institute of Environmental Health Sciences (NIEHS) (Grant number R01ES019624).
- Recruited 1,640 Rotorua residents (aged 18-65 yrs) living in areas with widely varying levels of exposure to H<sub>2</sub>S.
- Data were collected in 2008-2010.

# Main health outcomes of the study

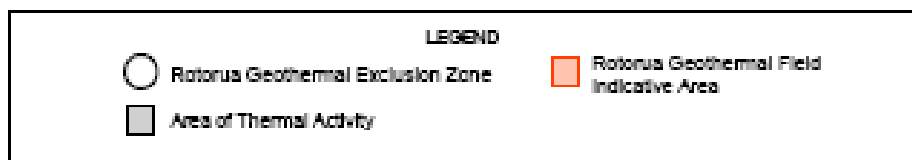
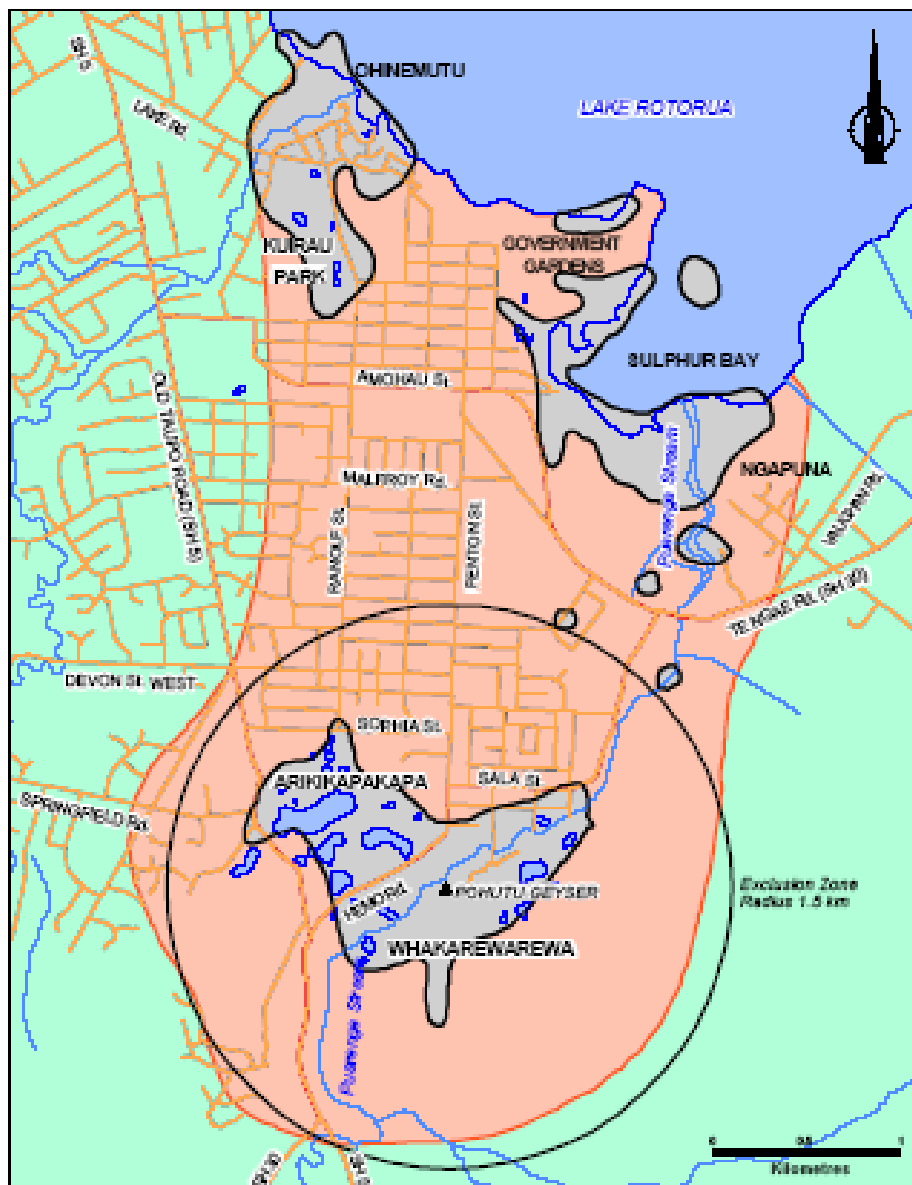
- Neuropsychological (cognitive) function
- Peripheral nerve function
- Respiratory function
- Cataract of the eye

# The questionnaire--components

- Residential history in Rotorua, last 30 years
- Workplaces in Rotorua, last 30 years
- Schools in Rotorua, last 30 years
- Medical history
- Smoking history
- Alcohol consumption history
- Race/ethnicity, education, income
- Opinions, good or bad, about the geothermal emissions in Rotorua



FIG 3: LOCATION OF MAIN AREAS OF THERMAL ACTIVITY



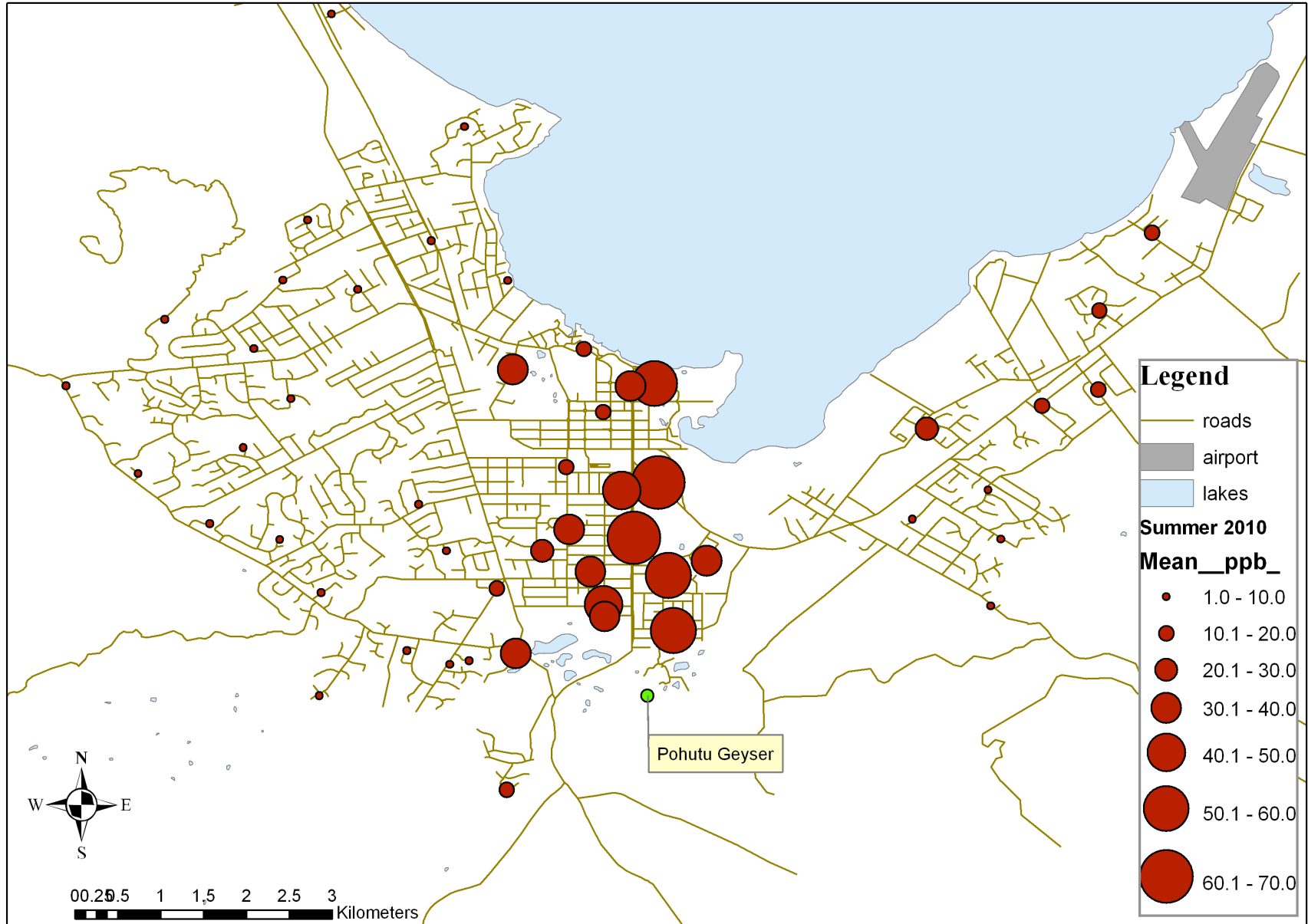


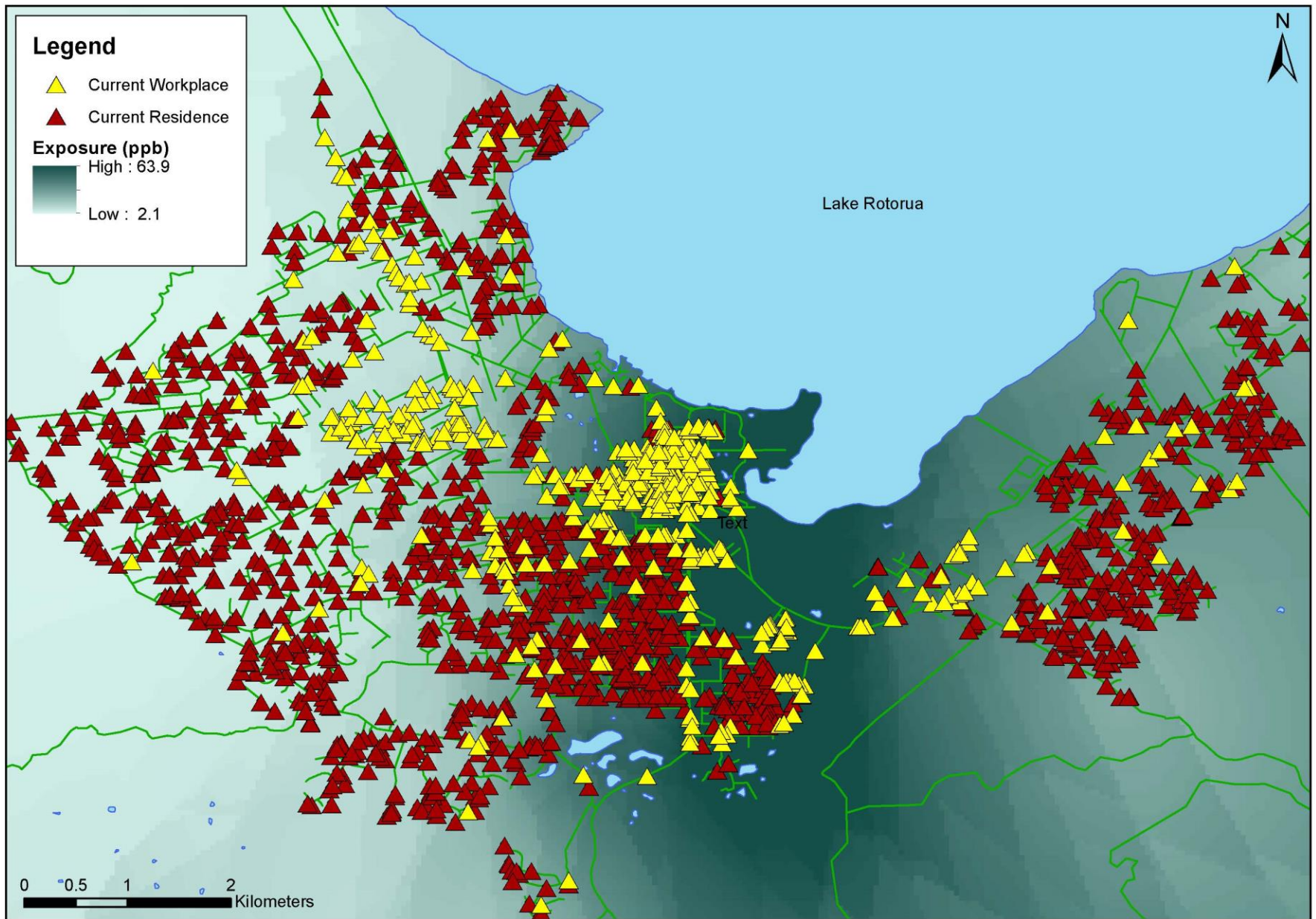
# Exposure assessment

- Radiello passive H<sub>2</sub>S monitors set out for 2 weeks, mainly at homes of a widely distributed sample of 50-60 study participants
- Monitoring in:
  - summer 2010
  - winter 2010
  - winter 2011
- Residential, workplace and school locations over last 30 years all geocoded
- Combine geocoding and monitoring results to create an individual H<sub>2</sub>S exposure profile for each participant

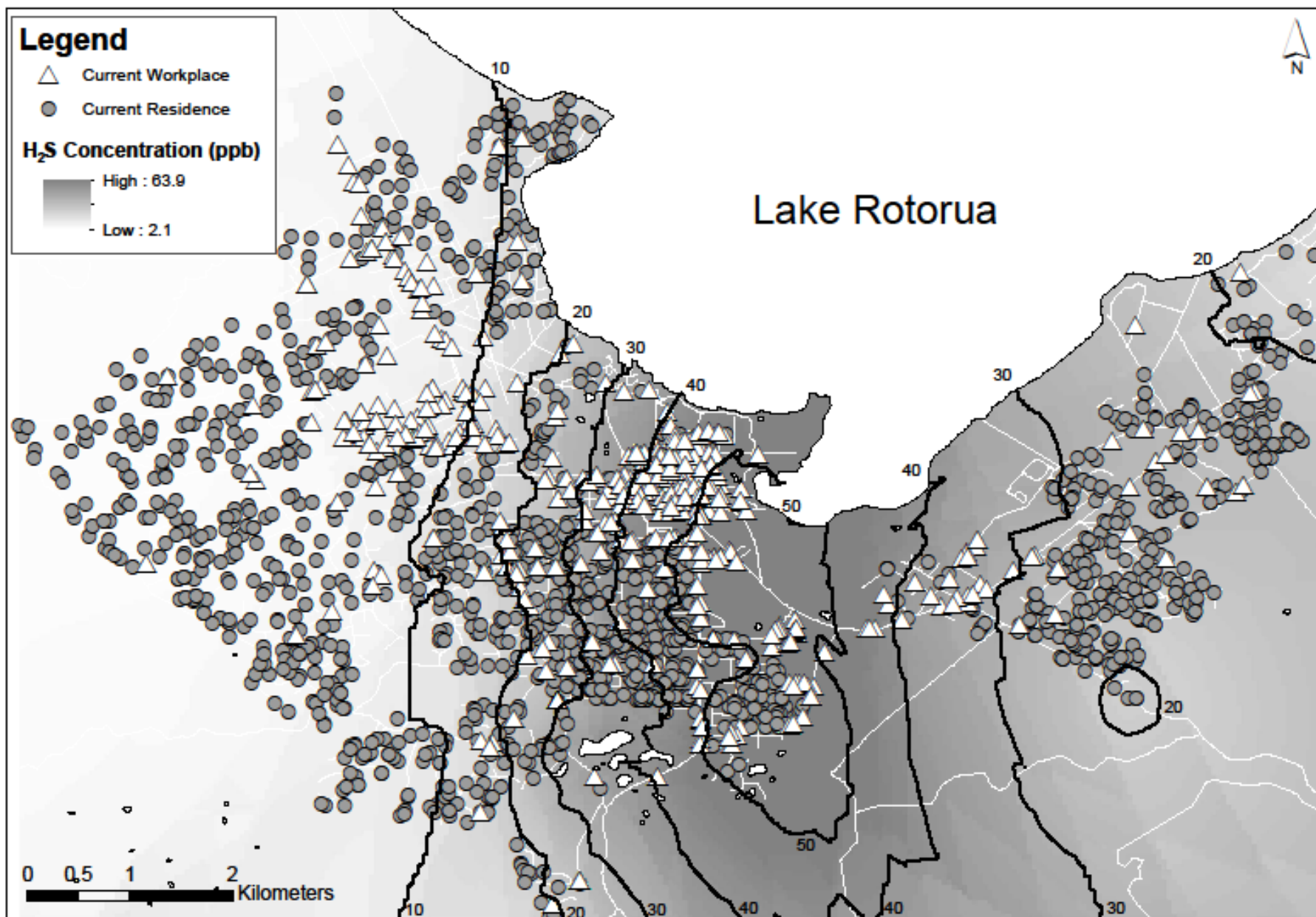


# Rotorua with original sampling selections and results from actual sites (homes) for H<sub>2</sub>S, summer 2010





Current homes and workplaces of study participants

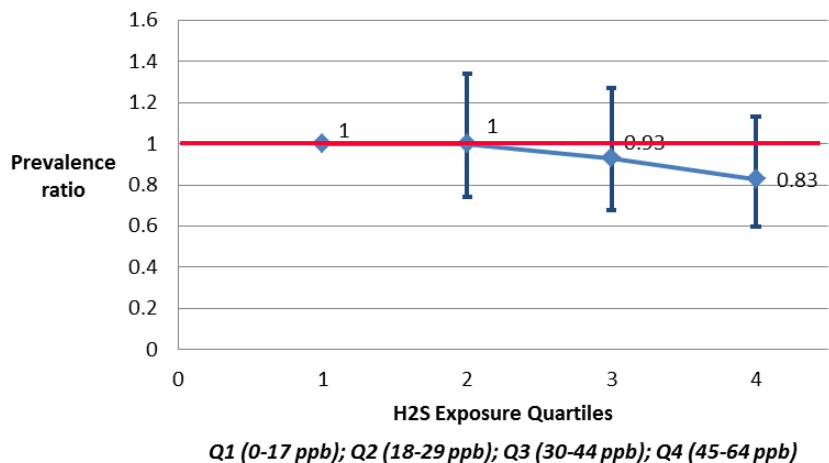


# Summary of Rotorua study results

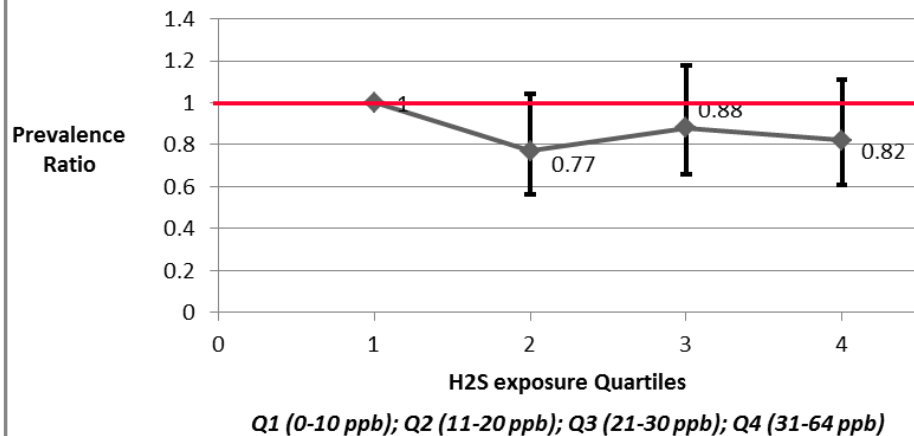
- 5 main publications, 2013-2017
- No evidence that H<sub>2</sub>S exposure was associated with cataract of the eye or effects on the central or peripheral nervous systems.
- Some evidence that higher exposures to H<sub>2</sub>S in Rotorua were associated with reduced prevalence of asthma and asthma symptoms, and improved lung function.

# Adjusted prevalence ratios (95% confidence intervals) for current asthma.

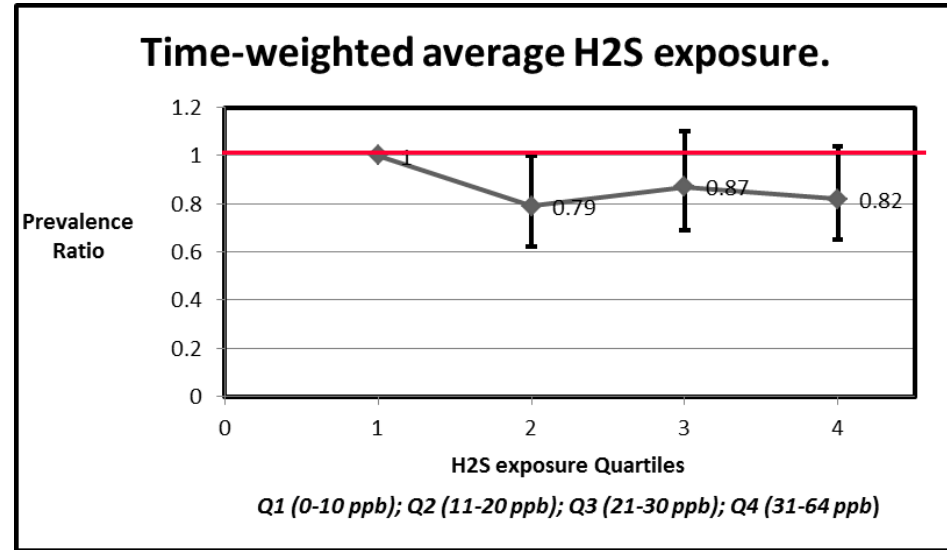
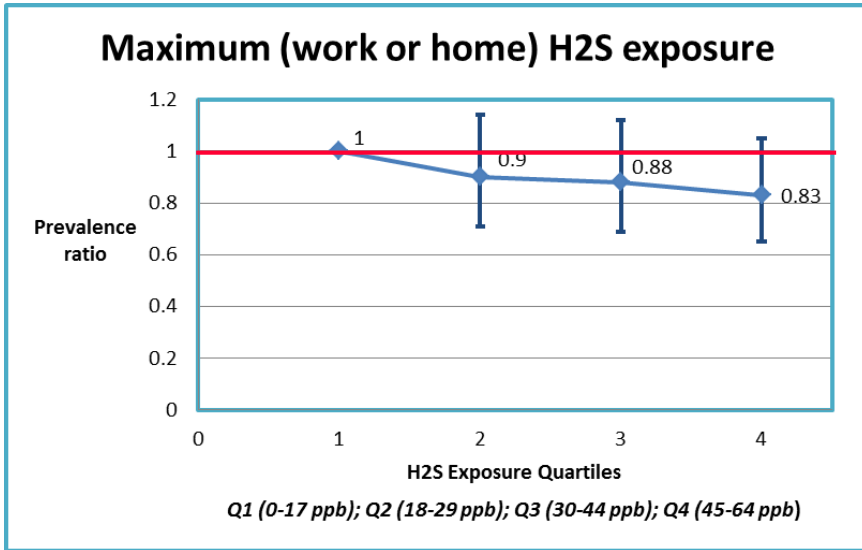
### Maximum (work or home) H2S exposure



### Time-weighted average H2S exposure.



# Adjusted prevalence ratios (95% confidence intervals) for ever diagnosed with asthma.



## Rapidly increasing science literature showing :

- $\text{H}_2\text{S}$  is an important, naturally produced, signalling molecule in the body ('gasotransmitter')
- Very low physiologic levels of  $\text{H}_2\text{S}$  can:
  - relax smooth muscles
  - reduce blood pressure
  - Increase antioxidant enzymes in the body
  - reduce metabolic rate
  - reduce inflammation
- Various medical and surgical uses of  $\text{H}_2\text{S}$  are being considered by medical scientists.



However, ...

- Studies so far have mostly been carried out in animals.
- Human research (e.g., epidemiology or clinical studies) data are very limited.

## Recent H<sub>2</sub>S studies from Iceland

Recent studies from Iceland have concluded that there is evidence for:

- An increase in prescriptions for anti-asthma drugs 3-5 days following spikes of H<sub>2</sub>S in Reykjavik.
- An increase in mortality and emergency hospital visits for heart disease on days that H<sub>2</sub>S concentrations are  $> 7\mu\text{g}/\text{m}^3$
- Increases in risk of several cancer types (breast, prostate, kidney, and non-Hodgkins lymphoma) in users of geothermal waters and people living in geothermal areas (bathing, bathing and washing).

## Conclusions

Further investigations are needed:

- (1) to confirm the results of the Rotorua study
- (2) to extend the Rotorua study to include cardiovascular outcomes
- (2) to confirm the outcomes of the Iceland studies, including resolving discrepancies with the Rotorua study (i.e., asthma)

Grazie mille!

